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Analysis Of Ground Cable Leakage Current Of Transformer 4 In North Bandung Substation

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Abstract

Monitoring leakage current in transformer power cables is crucial to prevent system failures and potentially dangerous electrical accidents. Leakage current in cables can damage equipment, pose a fire risk, and even lead to fatal accidents. One such incident is thermal failure caused by excessive heat in the cable. Leakage current monitoring is performed using an ammeter and thermovision , and the monitoring schedule is carried out weekly. Then, calculations are carried out using the thermal failure method followed by comparing the leakage current through calculations with direct measurements. The study was conducted to compare the measured leakage current values with the leakage current values calculated using the thermal failure calculation method at the North Bandung Substation. From the results of the leakage current calculations through thermal failure calculations and direct measurements, there are differences. The leakage current value closest to the standard value is in phase S4 with a leakage current value of 0.38 A (38% of the standard value and 0.066% of the nominal secondary current value).

Kata Kunci: *Leakage Current, Thermal Failure, Power Transformer Cable, Substation*

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INTRODUCTION

One of the essential components of an electrical power system is the grounding cable, particularly the 20kV grounding cable used in substations. This cable plays a critical role in transmitting electrical power safely from the substation to the distribution network while protecting both equipment and personnel from electrical faults (Kilis, 2021). The performance, safety, and reliability of the 20kV grounding cable are therefore fundamental to the overall stability of the power system, making it a key focus for engineering maintenance and safety protocols (Sitanggang & Prabowo, 2022).

A primary concern in grounding cables is leakage current, which occurs when electrical current flows unintentionally to the ground due to poor insulation, defects, or aging of the cable (Kilis, 2021; Sitanggang & Prabowo, 2022). Leakage currents can cause serious hazards, including equipment damage, fire risk, and potential fatal accidents for personnel (Zhang et al., 2018). Understanding the underlying mechanisms of leakage currents is therefore crucial for developing preventive strategies and improving operational reliability.

One significant factor contributing to leakage current is thermal failure. Thermal failure occurs when the rate of heat generation in a specific section of the cable exceeds the rate at which heat can dissipate, leading to insulation degradation and increased susceptibility to leakage (Erhaneli & Musnadi, 2013). Thermal failure not only accelerates cable aging but also reduces the service life of the grounding cable, increasing maintenance costs and operational risks (Chen et al., 2019). Research has shown that thermal effects in high-voltage cables can produce localized hot spots that intensify insulation breakdown, ultimately increasing the magnitude of leakage currents (Li et al., 2020).

Despite the importance of grounding cable performance, previous studies have gaps that warrant further investigation. First, Kilis (2021) highlighted the general risk of leakage currents but did not quantify the relationship between thermal effects and leakage magnitude in 20kV grounding cables. Second, Erhaneli & Musnadi (2013) examined thermal failures but primarily in laboratory conditions rather than in operational substation environments, limiting the applicability of their findings. Third, Sitanggang & Prabowo (2022) identified leakage current sources in cables but did not conduct precise accuracy analyses to compare measured leakage with transformer nominal currents. These gaps indicate a need for empirical studies that combine real-world substation measurements with precision analysis to evaluate both leakage current levels and their implications for system safety.

In addition, modern electrical systems increasingly rely on high-voltage substations for uninterrupted power supply, making grounding reliability more critical than ever. According to Zhang et al. (2018), systematic analysis of cable insulation and leakage current in operational conditions is necessary to mitigate potential risks and extend the lifespan of critical infrastructure. Moreover, Chen et al. (2019) emphasize that preventive maintenance strategies based on accurate leakage current measurements can significantly enhance both safety and economic efficiency by reducing unexpected outages and equipment failure.

Based on the identified gaps and the critical role of 20kV grounding cables, this study aims to analyze leakage currents in 20kV grounding cables at a substation, specifically considering thermal failure as a key factor. The research involves measuring leakage currents using standard techniques and comparing these measurements to the nominal secondary current of Transformer IV at the North Bandung Substation. Furthermore, a precision and accuracy analysis is conducted to determine the actual level of leakage current and its potential risk to the electrical system. The results of this study are expected to contribute to improved maintenance strategies, enhanced cable reliability, and greater overall safety in high-voltage substation operations.

METHOD

Leakage Current Measurement of Grounding Cable of Transformer 4, North Bandung Substation

Leakage current measurement is a routine weekly monitoring activity. At the North Bandung Substation, leakage current monitoring is carried out every Thursday.

The tool used to measure leakage current in grounding cables is an ampere clamp as seen in Figure 1.

Figure 1Ampere Clamp Used for Leakage Current Measurement

This ampere clamp measures the grounding cable for phases R, S, T. Determining the cable number on each phase (for example to determine the position of R1, R2, R3, R4 on phase R) is clockwise starting from the front left position. The leakage current measurement process is shown in Figure 2.

Figure 2Leakage Current Measurement Process of Transformer 4 at North Bandung Substation

Leakage current measurements for grounding cables at the North Bandung Substation are performed using a grounding system, connecting one end of the grounding system to the ground and the other end to the system or component being measured. If current leaks from the grounding cable , it will flow through the grounding system and into the ground, rather than through potentially hazardous equipment or the environment.

Direct measurement of leakage current under load conditions . The magnitude of the leakage current can be seen directly on the ampere clamp.

Furthermore, the data obtained from the leakage current measurement results are processed and compared with the leakage current standards at the North Bandung Substation.

CALCULATION AND DATA COLLECTION

Transformer Nominal Current Calculation

As seen in Figure 3, the transformer used in this calculation uses the 4 North Bandung Substation transformer with the specifications of Transformer IV UNINDO 60MVA 150/20 kV YN yn0(d1) 12.28%.

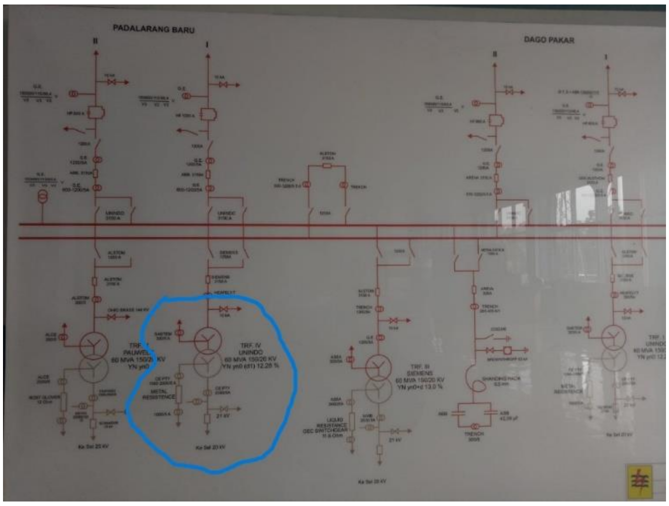

Figure 3Specifications of Transformer 4 North Bandung Substation

150/20kV is the primary and secondary voltages. 60MVA is the power, which is measured in MVA, meaning apparent power.

Table 1 . Transformer Group Vector Connections

Pergeseran Phasa	Koneksi (Vektor Group Trafo)		
0	Yy0	Dd0	Dz0
30 lag	Yd1	Dy1	Yz1
60 lag		Dd2	Dz2
120 lag		Dd4	Dz4
150 lag	Yd5	Dy5	Yz5
180 lag	Yy6	Dd6	Dz6
150 lead	Yd7	Dy7	Yz7
120 lead		Dd8	Dz8
60 lead		Dd10	Dz10
30 lead	Yd11	Dy11	Yz11

Figure 4. Transformer clock leg and lead zones

Vector The group used is the relationship vector YNyn0(d1). Vector This group means that the high voltage winding is connected in star and the neutral is removed, the low voltage winding is connected in star and the neutral is removed. Shift The phase is 0º or 00 o'clock. Meanwhile, the tertiary winding is connected in delta with a phase shift of 30 ^{0} at 1 o'clock. 12.28% is the percentage of impedance, how much resistance the transformer has to the current. The formula used to calculate apparent power can be seen in the following equation.

$$S = \mathrm{VxIx}\sqrt{3}$$

Information:
S: Apparent Power
V: Voltage
I: Current

From the formula above , the nominal I (current) value of the transformer on the primary and secondary sides can be calculated as follows.

Calculating Ip (primary side nominal current):

$$I_p = \frac{S}{Vx\sqrt{3}}$$

Calculating Is (secondary side nominal current):

$$I_s = \frac{S}{Vx\sqrt{3}}$$

Standard Deviation (Precision and Accuracy Test)

In performing manual calculations on the leakage current of the grounding cable of transformer IV, the standard deviation (SD) equation is used. The sample taken was 12 data on the leakage current of the grounding cable R, S, T of transformer IV of the North Bandung Substation. The standard deviation formula is as follows.

$$SD = \sqrt{\frac{\sum(Xn - X_{average})^2}{n-1}}$$

Information:
SD = Standard Deviation
X_n = Leakage Current (A)
$X_{average}$ = Average leakage Current
n = Number of data

To see the level of precision of a measuring instrument, it can be calculated using the following equation.

$$\text{Precision} = 100\% - \text{SD}$$

The level of accuracy can be calculated using the following equation.

$$\text{Accuracy} = 100\% - \%\text{error}$$

Information:

$$\%\text{error} = \left|\frac{\text{Reference Data} - \text{X}_{\text{average}}}{\text{Reference Data}}\right| \text{x}100\%$$

Reference data = Measured value/Value to be compared
$X_{average}$ = Average of the measured leakage current values

Calculation of Transformer Secondary Output Current (Is) and Transformer Primary Input Current (Ip)

To calculate the secondary transformer output current (Is) and the primary transformer input current with a known 3- phase load power of 60MVA, secondary phase-phase voltage of 20kV, primary phase-phase voltage of 150kV with a power factor of 0.85.

$$I_s = \frac{P_{3\emptyset}}{\sqrt{3}\, V_{LLs} \cos\emptyset}$$

$$I_s = \frac{60000}{\sqrt{3}.20.\cos(0{,}85)}$$

$$I_s = 2620A$$

Turn ratio:

$$a = \frac{V_{LLp}}{V_{LNS}}$$

$$a = \frac{150}{11{,}55}$$

$$a = 12{,}987$$

Transformer primary current:

$$I_p = \frac{1}{a}.I_s$$

$$I_p = \frac{1}{12{,}987}x2620$$

$$I_p = 226{,}84$$

The results obtained are that the secondary transformer output current (Is) is 2620A and the primary transformer input current (Ip) is 226.84 A.

Transformer Nominal Current Calculation

The transformer used in this calculation is the 4th transformer from the North Bandung Substation with the specifications of Transformer IV UNINDO 60MVA 150/20 kV YN yn0(d1) 12.28%. Therefore, the calculation is as follows:

Calculate Ip (primary side nominal current) with the following equation:

$$I_p = \frac{S}{Vx\sqrt{3}}$$

$$I_p = \frac{60000}{150x1{,}732}$$

$$I_p = 230{,}95A$$

Calculate Is (nominal current of the secondary side) with the following equation:

$$I_s = \frac{S}{Vx\sqrt{3}}$$

$$I_s = \frac{60000}{20x1{,}732}$$

$I_s = 1732,1A$

Percentage of Leakage Current to Transformer Input Current (Ip)

The percentage of leakage current to the primary transformer inrush current does not have a general formula because it can vary depending on many factors such as transformer design, material characteristics, applied voltage, and others. Leakage current is usually very small compared to the primary inrush current.

$$I_{leakage} = \frac{I_{leakage}}{I_p} x100\%$$

$$I_{leakage} = \frac{0,3}{226,84} x100\%$$

$$I_{leakage} = 0,132\%$$

Table 1. Percentage Of Leakage Current To Primary Input Current Of Transformer

Phase	*Core Cable*	Direct Measurement	Percentage of leakage current to primary transformer input current (Ip)
R	R1	0.3	0.132%
	R2	0.18	0.079%
	R3	0.23	0.101%
	R4	0.17	0.075%
S	S1	0.14	0.062%
	S2	0.17	0.075%
	S3	0.27	0.119%
	S4	0.38	0.168%
T	T1	0.21	0.093%
	T2	0.19	0.084%
	T3	0.31	0.137%
	T4	0.2	0.088%

The percentage of leakage current relative to the primary transformer inrush current is generally very small, typically less than 1% of the primary inrush current. This is due to the low capacitance between the transformer windings and the voltage applied to the capacitive path. Good transformer design, proper insulation, appropriate material selection, and balanced load arrangement also contribute to low leakage current. The combination of these factors results in relatively insignificant leakage current during normal transformer operation.

Comparison of Leakage Current Values

Next, we'll compare the leakage current value during direct measurement with the existing leakage current standard, 1 Ampere. We'll also compare the leakage current value from direct measurement with the nominal value on the secondary side.

Table 3. Comparison of leakage current measurements with leakage current standards

Phase	*Core Cable*	Leakage Current Standard	Direct Measurement
R	R1	1A	0.3 A
	R2	1A	0.18 A
	R3	1A	0.23 A

	R4	1A	0.17 A
S	S1	1A	0.14 A
	S2	1A	0.17 A
	S3	1A	0.27 A
	S4	1A	0.38 A
T	T1	1A	0.21 A
	T2	1A	0.19 A
	T3	1A	0.31 A
	T4	1A	0.2 A

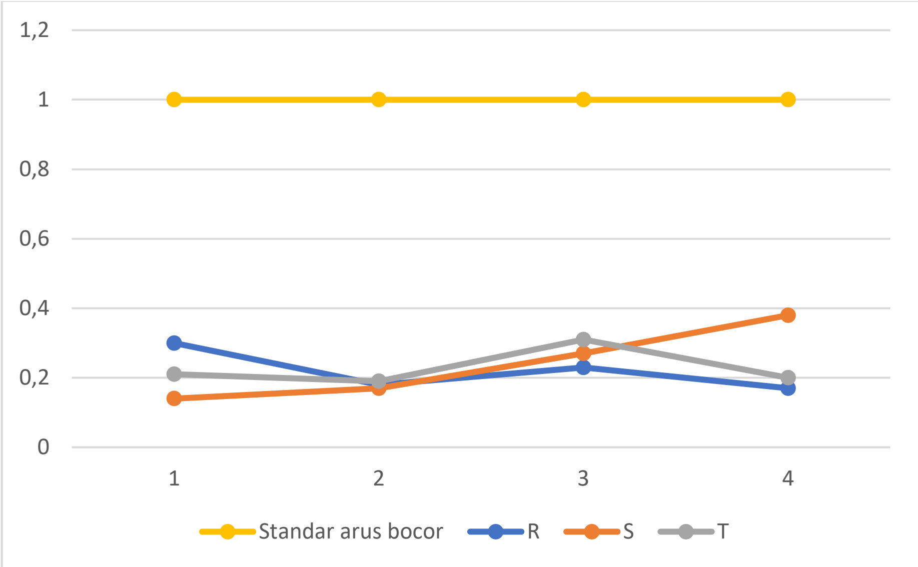

Figure 4Comparison Of Leakage Current Measurement With Leakage Current Standard

Next we will compare the leakage current value directly with the nominal current value on the secondary side.

Table 2Comparison Of Leakage Current Measurements With Nominal Current On The Secondary Side

Phase	*Core Cable*	Nominal current	Direct Measurement	Percentage of leakage current to nominal current
R	R1	577.4 A	0.3 A	0.052%
	R2	577.4 A	0.18 A	0.031%
	R3	577.4 A	0.23 A	0.040%
	R4	577.4 A	0.17 A	0.029%
S	S1	577.4 A	0.14 A	0.024%
	S2	577.4 A	0.17 A	0.029%
	S3	577.4 A	0.27 A	0.047%
	S4	577.4 A	0.38 A	0.066%
T	T1	577.4 A	0.21 A	0.036%
	T2	577.4 A	0.19 A	0.033%
	T3	577.4 A	0.31 A	0.054%
	T4	577.4 A	0.2 A	0.035%

It can be seen from the table and graph that the leakage current value is still below the existing leakage current standard so that no action is required . The leakage current value closest to the standard value is in phase S4 with a leakage current value of 0.38 A (38% of the standard value and 0.066% of the nominal secondary current value).

Precision and Accuracy Test with Standard Deviation

Measurements and data collection of the grounding current of the transformer IV grounding cable at the North Bandung Substation were conducted on June 2, 2022. The measurements were made using an ampere meter. To determine the precision of the measuring instrument, the author analyzed it using the Standard Deviation (SD).

The following is a description of the Standard Deviation (SD) values taken from the leakage current values from the R, S, T phases of the transformer IV of the North Bandung Substation as follows:

Arithmetic The mean can be found using the following equation:

$$X_{average} = \frac{\sum X_n}{n}$$

$$X_{average} = \frac{0{,}30 + 0{,}18 + 0{,}23 + 0{,}17 + 0{,}14 + 0{,}17 + 0{,}27 + 0{,}38 + 0{,}21 + 0{,}19 + 0{,}31 + 0{,}20}{12}$$

$$= 0{,}229166667\ \mathrm{A}$$

The results obtained from arithmetic calculations The mean leakage current of the grounding cable of the transformer IV of the North Bandung Main Station is 0.229166667 A. Then the next calculation is the difference between the measured value of the leakage current and the arithmetic value. mean as follows:

Data 1:

$$X_n - X_{average} = 0{,}30 - 0{,}229166667 = 0{,}0708$$

$$(X_n - X_{average})^2 = 0{,}0708^2 = 0{,}005017$$

Table 5. Leakage Current Data For Transformer Grounding Cable IV

No	Leakage Current Measurement(Xn)(A)	(Xn - Xaverage)	(Xn - Xaverage) 2
1	0.3	0.0708	0.005017
2	0.18	-0.0492	0.002417
3	0.23	0.0008	0.000001
4	0.17	-0.0592	0.003501
5	0.14	-0.0892	0.007951
6	0.17	-0.0592	0.003501
7	0.27	0.0408	0.001667
8	0.38	0.1508	0.022751
9	0.21	-0.0192	0.000367
10	0.19	-0.0392	0.001534
11	0.31	0.0808	0.006534
12	0.2	-0.0292	0.000851
Average	0.229166667	∑(Xn - Xaverage) 2	0.056092

The total amount of the difference between the measured values of leakage current and arithmetic mean as follows:

$$\sum(X_n - X_{average})^2$$
$$= 0{,}005017 + 0{,}002417 + 0{,}000001 + 0{,}003501 + 0{,}007951 + 0{,}003501 + 0{,}001667 + 0{,}022751 + 0{,}000367 + 0{,}001534 + 0{,}006534 + 0{,}000851$$
$$\sum(X_n - X_{average})^2 = 0{,}056092 \text{ A}$$

The standard deviation formula states the level of precision of a measuring instrument which can be seen in equation (5.4) as follows:

$$SD = \sqrt{\frac{\sum(X_n - X_{average})^2}{n-1}}$$
$$SD = \sqrt{\frac{0{,}056092}{12-1}} = 0{,}071409 \text{ A}$$

To see the level of precision in percentage form as follows:

$$\text{Precision} = 100\% - SD = 99{,}928591\%$$

After obtaining the precision value, the author performed a calculation to test the leakage current accuracy against the nominal current value on the secondary side of the transformer. A percentage error value is required to calculate the accuracy level. The reference data is the nominal current value on the secondary side of the transformer, which is 1732.1 A. The percentage error calculation uses the following equation:

$$\%error = \left|\frac{\text{Reference Data} - X_{average}}{\text{Reference Data}}\right| x100\%$$
$$\%error = \left|\frac{1732{,}1 - 0{,}229166667}{1732{,}1}\right| x100\% = 0{,}999867694\%$$

Next, the calculation to obtain the percentage of accuracy level is as follows:

$$\text{Accuracy} = 100\% - \%error = 100\% - 0{,}999867694\% = 99{,}00013231\%$$

From the results, it can be seen that the IV transformer grounding cable leakage current measuring instrument has high precision and accuracy, meeting SI standards, where the precision and accuracy are >97%.

The table and graph show that the leakage current value is still below the existing leakage current standard, so no action is required . The highest leakage current value relative to the nominal secondary current is in Phase S4 at 0.066% of its nominal current value.

Several factors that can cause the leakage current in phase S4 to have the highest value compared to other phases include humidity, contamination such as dust, dirt or chemicals that stick to it, physical factors of the cable and environmental influences such as high temperatures.

CONCLUSION

The process of monitoring the leakage current on the grounding cable at Transformer 4 of the North Bandung Substation is carried out periodically through a measurement method using an ampere clamp and thermovisi instrument . Based on the results of data analysis, it is known that the nominal current on the primary side is 230.95 A and the secondary side is 1732.1 A, with the calculation results of the actual current flowing of 226.84 A on the primary side and 2620 A on the secondary side. The research findings show that the percentage of leakage current to the primary incoming current is very small, which is below 1%, which is caused by the low capacitance between the transformer windings and the influence of voltage on the capacitive path.

All measured leakage current values are still below the applicable standard threshold at the North Bandung Substation, with the highest value recorded in phase S4 at 0.38 A or only 0.066% of its nominal current. Evaluation of the monitoring device shows excellent performance with a precision level reaching 99.928% and an accuracy of 99.000% of the secondary nominal current. Thus, the grounding cable leakage current measuring instrument on Transformer 4 is stated to have a high level of precision and accuracy that has met international standards (SI) with a value above 97%, so it is very suitable for use as an instrument for monitoring the reliability of the electric power system.

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